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Status of Solidification/Stabilization in the United States and Factors Affecting Its Use

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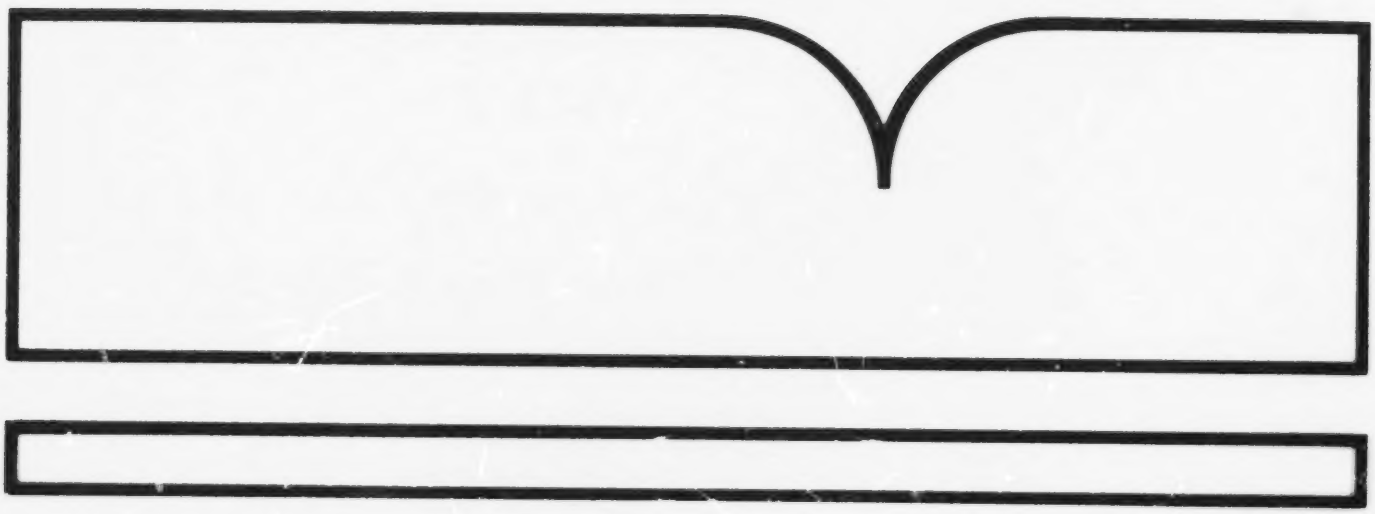

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16. ABSTRACT

This paper reviews the status of using solidification/stabilization to treat hazardous waste and contaminated soil in the United States. Technical and regulatory factors affecting use of the technology are also discussed. Selected U.S. Environmental Protection Agency research projects are highlighted.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

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STATUS OF SOLIDIFICATION/STABILIZATION IN THE UNITED STATES AND FACTORS AFFECTING ITS USE

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1. INTRODUCTION

Solidification/stabilization (S/S) technology has been used for over 20 years to treat U.S. industrial waste.

1.1 Solidification/Stabilization Technology

1.1.1. Definitions. Definitions for S/S technology vary depending upon the source. In very general terms, S/S, as it relates to managing hazardous waste, refers to a technology where one uses additives or processes to transform the waste into a more manageable form or less toxic form by physically and/or chemically immobilizing the waste constituents. It is important to understand the terminology being used in order to properly evaluate the technology for potential application.(1)

1.1.2. Objectives. The broad objective of S/S technology is to contain a waste contaminant and prevent it from entering the environment. In practice this broad objective may be realized by several mechanisms which include producing a solid; improving the handling characteristics of the waste; decreasing the surface area across which the transport of the contaminant may occur; and, limiting the mobility of the contaminant when exposed to leaching fluids. The ideal objective is to chemically transform the toxic contaminant into a non-toxic form. Realistically, chemical changes of the contaminant do not routinely occur with available state-of-the-art S/S technologies. More vendors, however, are claiming that chemical bonding does take place rather than or in addition to microencapsulation.

1.1.3. Binders and Binding Mechanisms. Binder systems can be placed into two broad categories, inorganic or organic. Most inorganic binding systems in use include varying combinations of hydraulic cements, lime, pozzolans, gypsum, and silicates. Organic binders used or experimented with include epoxy, polyesters, asphalt/bitumen, polyolefins (primarily polyethylene and polyethylene-polybutadiene), and urea-formaldehyde. Combinations of inorganic and organic binder systems have been used. These include diatomaceous earth with cement and polystyrene; polyurethane and cement, and polymer gels with silicate and lime cement.(2) Examples of reactions which cause the binding or containment of

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the contaminant are sorption, lime-fly ash pozzolan reactions, pozzolan Portland cement reactions, thermoplastic microencapsulation, and vitrification.(3)

1.1.4. Process Types. Solidification process types normally found in the U.S. are: in-drum processing, in-plant processing, mobile plant processing, and in situ processing. Combinations of these process types may be used depending upon specific requirements at a given site. In the case of a contaminated soil area, in situ and mobile type of processes are most often used.

1.2. Current Status of S/S in the U.S.

Although S/S has seen significant use for treating waste in the U.S., there are technical and regulatory factors which may greatly affect its future use. U.S. EPA regulations and proposed regulations controlling the treatment and disposal of hazardous waste and contaminated soil and debris will be the major factor determining how much S/S technology will be used. Because of this, the U.S. EPA is investigating S/S of waste.(4) The remaining portions of this paper will further discuss the U.S. EPA S/S programs and the factors important in determining how much S/S will be used in the future in the U.S.

2. THE U.S. EPA PROGRAM IN SOLIDIFICATION/STABILIZATION.

The U.S. EPA programs in S/S include evaluating S/S as a best demonstrated available technology for treating hazardous waste, evaluating S/S for treating contaminated soil and debris, and conducting research to develop a more comprehensive scientific understanding of the technology.

2.1. Research.

The current U.S. EPA research (Table 1) has emphasized investigating interferences to S/S, investigating waste-binder interaction and waste disposition sites, and study of methods for predicting performance of S/S products.

2.1.1. Interfering Agents. Research on interfering agents will provide data on the effects that interfering inorganics (Pb, Cd, Zn, sulfates, etc.) and organics (oil, grease, HCB, TCE, phenol) may have on generally used pozzolanic binder systems. The information will be useful in evaluating applications for delisting hazardous waste and for permits to treat hazardous wastes with S/S, particularly for those waste streams contaminated with organics. This information and that from research on factors critical to S/S will also aid decisions on potential waste pretreatment techniques for enhancing S/S performance. Data from physical and chemical tests is being analyzed to determine if a correlation exists between physical properties of the solidified waste form and its ability to resist stresses when exposed to leaching situations.

TABLE 1. Current U.S. EPA Solidification/Stabilization Research Projects

Project Title	Objective	Status
Evaluation of Factors Affecting Solidification/ Stabilization of Toxic Waste	Determine effects of interfering agents on performance of S/S	Data interpretation ongoing
Investigation of Test Methods for Soldified - Waste Characterization - A Cooperative Program	Develop and evaluate methods for testing performance of solidification processes	Data interpretation ongoing
Study of Morphology and Microchemistry of Solidified/ Stabilized Waste	Investigate bonding mechanisms	Research is continuing
Morphological Examination of S/S Samples from Canadian - US and other studies	Morphological examination of solidified waste specimens; correlate results with physical/ chemical test of actual samples	Ongoing
Critical Characteristics of Hazardous Waste Solidification/ Stabilization	Identify physical and chemical characteristics of waste and binders affecting S/S	Being expanded to provide QA/QC information
Air Emissions from Waste Stabilization	Determine air emissions from S/S processes	Ongoing
Evaluation of S/S for Treating Ash Residues	Evaluate S/S of residues from combusting municipal solid waste	Ongoing

2.1.2. Evaluating Test Methods. An effort with Canada is emphasizing evaluation of several leaching tests for determining the extent of toxic constituent binding. Protocols for examining physical properties are also being evaluated. This research includes actual waste and synthetic sludges solidified by vendors. Information on the performance of several different solidified products can be compared. This research will provide important data to compare current U.S. EPA regulatory leaching procedures with others being tested.

2.1.3. Morphological Studies. Electron scanning and x-ray defraction microscopy techniques and solvent extractions are being used to investigate waste/binder interactions. The objective is to better understand S/S by identifying binder reaction phases where the waste components concentrate their form, and is bonded. Concurrent with this research, specimens of solidified waste from other research projects are being examined in efforts to correlate results of physical and chemical tests with performance of S/S products. Results from these specific studies have indicated that physical entrapment of inorganic metals is a predominant containment mechanism. However, some results are also indicating formation of altered or new crystal strutures in some phases which appear to be chemically bonding some organics. Indications are that this type research could provide information useful in preparing binder formulations better able to treat a specific waste.

2.1.4. Critical Characteristics. The physical and chemical characteristics of the waste affect the performance, as do the climatic (temperature and humidity) conditions at the time of placement and curing. The research on critical characteristics is being expanded to develop information on what quality assurance/control procedures are needed to better assure adequate performance of S/S when applied in the field. This information is especially important for the remediation of contaminated soils with varying characteristics and field treatment projects requiring more than one season.

2.1.5. Air Emissions. Because of the nature of many solidification processes, uncontrolled air emissions are a potential problem to workers and the environment. Investigations are being conducted to determine the magnitude of these air emissions. Processes being evaluated are Portland cement - fly ash and lime kiln dust - fly ash mixtures. As expected, mixing causes the greatest air emissions. Some additives such as lime result in exothermic reactions which increases the release of volatile compounds. Capture and treatment of these emissions may be required to protect worker health and the environment, particularly in cases where the waste or contaminated soils contain volatile compounds.

2.1.6. Leaching Procedures. A variety of leaching tests are used to predict how well the solidified waste form will prevent the release of contaminants over time. To assure the proper use of these procedures, an effort (not shown on Table 1) is being initiated to compile and evaluate available information on the procedures to determine the correct use, how well each performs its intended function, and which ones are best suited to better predict long term performance. This is especially important for the proper design of S/S processes for remediating contaminated soils and debris.

2.1.7. Solidification of Municipal Waste Combustion Ashes. Ashes from the combustion of municipal waste may contain unacceptable levels of heavy metals, particularly lead and cadmium. Solidification/ stabilization technology is being evaluated as an acceptable technique to control leachate from the ashes if required.

2.2 Evaluation of S/S as an Available Treatment Technology.

2.2.1. Treatment of Hazardous Wastes. In the United States, the Hazardous and Solid Waste Amendments (HSWA), which amended the Resource Conservation and Recovery Act (RCRA) provide detailed procedures dictating how hazardous waste is defined, controlled, and managed. Wastes classified as hazardous under RCRA are often referred to as RCRA hazardous waste. Key provisions of HSWA are the ones which ban the land disposal of hazardous waste unless it is proven to be more protective of the environment and human health than other alternatives. The legislation requires that all hazardous waste be treated by the best demonstrated available treatment (BDAT) instead of and prior to land disposal. The U.S. EPA is required to determine and specify levels to which BDAT technologies can treat RCRA waste. Solidification/stabilization is one of several BDAT technologies being evaluated. In this program selected hazardous wastes are solidified/stabilized by Portland cement, cement kiln dust, and lime/fly ash mixtures. Various ratios of waste to binder for each binder system is then evaluated by the Unconfined Compressive Strength Test (UCS) after a cure time of 7, 14, 21, and 28 days. Cured samples are then subjected to the USEPA's Toxicity Characteristic Leaching Procedure (TCLP) extraction test. Leachate from the TCLP is analyzed for the pollutants of concern (see Table 2), to determine how effective S/S can be for treating selected hazardous waste. Results will be important in determining how much S/S will be used to treat hazardous waste in the U.S.

TABLE 2. Examples of U.S. RCRA Hazardous Wastes for Which S/S is Being Evaluated as a Treatment Technology

Waste Code	Description of Waste	Pollutant of Concern
K048-52	Dissolved air flotation (DAF) float from the petroleum refining industry	Hexavalent chromium, lead
K061	Emission control dust/sludge from the primary production of steel in electric furnaces	Hexavalent chromium, lead, cadmium
K046	Wastewater treatment sludges from manufacturing, formulation, and loading of lead-based initiating compounds	Lead

2.2.2. Treatment of Contaminated Soils. The remediation of contaminated soils, hazardous waste uncontrolled dump sites, etc., is controlled under legislation referred to as the Superfund Amendments and Reauthorization Act (SARA) which amended the Comprehensive Environmental Reclamation Compensation Liability Act (CERCLA). Under SARA provisions, permanent treatment of the contaminated soil and debris is being emphasized rather than the use of nontreatment containment systems such as covers, grout walls, and similar methods. Because of this, a program similar to the RCRA BDAT evaluations is being conducted for SARA remediation technologies including S/S. Mixtures of soils contaminated with selected chemicals (Table 3) are solidified/stabilized and tested to evaluate performance of S/S technology for treating contaminated soils. The test soil being used is a mixture of clay, sand, silt, topsoil and aggregate.

TABLE 3. Contaminates Added to Test Soil Being Used to Evaluate Effectiveness of Solidification for Treating Soils

Metals	Volatiles	Semi-Volatiles
Lead	Acetone	Benzo (a) pyrene
Zinc	Ethylbenzene 1,2 Dichloroethane	Pentachlorophenol

TABLE 3. (cont'd) Contaminates Added to Test Soil Being Used to Evaluate Effectiveness of Solidification for Treating Soils

Metals	Volatiles	Semi-Volatiles
Cadmium	Xylene	Naphthalene
Copper	Tetrachloroethylene	
Nickel	Chlorobenzene	
Chromium		

2.3. Solidification/Stabilization Laboratory.

In conjunction with other evaluation programs, laboratory facilities and procedures have been established to test samples of solidified waste extracted from bench and pilot treatability studies and field operations. These facilities also assist in determining if a particular contaminated soil or waste is capable of being effectively solidified/stabilized by using a full range of leaching and physical tests. Data from this program will help investigators to extrapolate laboratory test results to better predict expected long term field performance.

2.4. Superfund Innovative Technology Evaluations (SITE).

The U.S. EPA SITE program provides for demonstration and evaluation of innovative technologies to remediate Superfund sites. Currently six S/S processes are being evaluated (Table 4). Results will provide information on how well S/S can be expected to permanently treat contaminated soils. The evaluations will also help make better extrapolation of laboratory tests results to field conditions.

TABLE 4. Solidification/Stabilization Processes Being Evaluated in the U.S. EPA SITE Program

Process Developer	Description
Chemfix Technologies, Inc.	Uses soluble silicate reagents and silicate-setting agents
Soliditech, Inc.	Uses pozzolanic agents, water and liquid reagents including URRICHEM. Claims to treat organics and inorganics
Waste Chem Corporation	Volume reduction and solidification using asphalt binder and extrusions. Claims to treat organics and inorganic metals

TABLE 4. (cont'd) Solidification/Stabilization Processes Being Evaluated in the U.S. EPA SITE Program

Process Developer	Description
Battelle Pacific NW	In Situ vitrification; thermal treatment to pyrolyze organics and immobilize inorganics in glass-like mass
Hazcon, Inc.	Uses Portland cement, fly ash, kiln dust and proprietary chemicals to treat organics and inorganics
International Waste Technologies	Uses silicate-colloid or inorganic polymers as medium; promotes absorption of organics; claims chemical bonding of organics; treats inorganics

3. PROCESS SELECTION CONSIDERATIONS

3.1. Important Factors.

Factors important in the selection, design, implementation, and performance of processes and products are: waste characteristics (chemical and physical), processing requirements, S/S product management objective, regulatory requirements, and economics. These and other site-specific factors (i.e., location, condition, climate, hydrology, etc.) must be carefully considered to ensure acceptable performance.

3.1.1. Waste Characteristics. The chemical effects of some compounds can reduce the strength of the binder/waste mix, while some compounds can accelerate or retard the S/S curing rate. Temperature and humidity can also retard or accelerate curing. Size and shape of the waste particles can affect the viscosity of the mix. Overmixing or undermixing can affect the product's strength. Waste characteristics are among the most important factors affecting S/S and inorganics usually can be more easily solidified/stabilized than can organics.

3.1.2. Process Type. It is important to assess what process type and specific process requirements are required before selecting an S/S technology. For example, a waste-binder can be controlled and mixed more easily in a drum or in a plant process than in the in-situ solidification of a pit, pond, or lagoon.

3.1.3. Treatment Objectives. How the solidified waste will be managed is important in selecting the best process to be disposed of in a landfill, or stored, or transported? Will it be placed in a plastic or metal drum below or above the water table? Stored in a warehouse or underground mine?

3.1.4. Regulatory Factors. Regulations in the United States will be critical to the success of S/S. Processes can be altered to meet different performance criteria, which will become increasingly stringent, as regulations become more stringent. S/S will be competing with other treatment technologies to meet these regulatory criteria.

3.1.5. Costs. Costs will depend on site-specific conditions. Important are the waste's characteristics, transportation, type of process, and other special factors. What is the physical form and chemical make-up of the waste? Is pretreatment needed? Is transportation of raw materials and/or finished S/S products required? Which S/S process is needed? What special health and safety requirements are needed? What is the quality assurance/quality control cost involved? What regulatory criteria must be met? Each of these factors must be considered. As regulatory criteria become more demanding, the costs of acceptable solidification processes may increase.

4. STUDIES NEEDED FOR S/S AS A TREATMENT TECHNOLOGY

For S/S technology to be effective in managing hazardous waste, proposed processes must be properly selected, formulated, and used. Improved knowledge of process selection considerations and the interactions among the various candidate binders and waste types is critical to the successful use as an acceptable treatment technology.

Studies are needed:

- to determine the long-term physical-chemical stability of S/S products when placed on the land;
- to determine how and under what conditions S/S products should be placed on the land to ensure long term environmental protection;
- to more accurately predict and measure the performance of S/S processes and products;
- to provide a correlation between regulatory criteria and real world situations;
- to evaluate the effectiveness of protocols (e.g., TCLP, other leaching tests, UCS, etc.) to characterize S/S products, provide effective measurement techniques, and correlate results of such tests with performance in the field;

- to determine the effectiveness of processes and equipment to effectively solidify/stabilize contaminated soil and/or lagoons; the effectiveness of mixing methods; and the resulting solidified/stabilized soil performance at varying soil depths;
- to determine the amounts of organic compounds that can be included in inorganic waste streams without requiring pretreatment before S/S;
- to determine how effectively S/S processes treat residuals compared to other alternative treatments.

5. SUMMARY

Solidification/stabilization is being evaluated by the U.S. EPA as a best demonstrated available technology for treating hazardous waste and contaminated soils and debris. Future use of the technology in the United States will depend on how well it performs compared to other available treatment processes. The evaluations and current research being conducted will provide some answers regarding performance, however, additional studies are required for a better scientific understanding of S/S. Whether or not S/S becomes an important technology for treating hazardous waste and contaminated soils in the U.S. ultimately depends upon regulatory requirements and the capability of the technology to meet these requirements. As performance criteria become more severe, S/S developers may need to improve their processes. The opportunity is very good. In the case of RCRA waste, S/S may be the only acceptable method to treat selected inorganic waste and hazardous residues from incinerators and other treatment processes. In the case of contaminated soils and debris, S/S offers a relatively inexpensive method for treating large areas in-situ. However, the capability of the technology to perform satisfactorily over long periods of time has yet to be determined.

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